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PHYSIOLOGICAL CORRELATES OF VIGILANCE PERFORMANCE.(U)

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

PHYSIOLOGICAL CORRELATES
OF
VIGILANCE PERFORMANCE

by

William Eric Coons

March 1977

Thesis Advisor: G.K. Poock

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REPORT DOCUMENTATION PAGE — READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 Physiological Correlates of Vigilance Performance.		5. TYPE OF REPORT & PERIOD COVERED 9 Master's Thesis, March 1977
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 William Eric Coons		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE 11 Mar 1977
		13. NUMBER OF PAGES 12 49p
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Vigilance, Monitoring, Sinus Arrythmia, Heart Rate, Depth Perception, Critical Flicker Fusion Frequency, Information Processing Rate, Detection Performance, Physiological Parameters

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This research is an investigation of the relationships between several physiological measures and vigilance performance. Heart rate and sinus arrythmia were measured throughout a 40-minute vigilance task for each of fifteen subjects. Information processing rate, depth perception and critical flicker fusion frequency were measured before and after the task. Significant results were found by

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(Page 1) S/N 0102-014-6601

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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Physiological Correlates of Vigilance Performance

by

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

Naval Postgraduate School
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ABSTRACT

This research is an investigation of the relationships between several physiological measures and vigilance performance. Heart rate and sinus arrythmia were measured throughout a 40-minute vigilance task for each of 15 subjects. Information processing rate, depth perception and critical flicker fusion frequency were measured before and after the task. Significant results were found by linear correlation techniques which showed pre-test depth perception and detection performance negatively correlated ($r = -.585$, $p < .025$), pre-test critical flicker fusion frequency and detection performance positively correlated ($r = .492$, $p < .05$), and heart rate positively correlated with detection performance ($r = .7703$, $p < .1$).

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I. INTRODUCTION

In general, vigilance can be described as a readiness to detect a stimulus event. Historically, studies of this phenomenon have centered on monitoring tasks in which the signal to be detected is a rarely and randomly occurring event as well as being small when compared to the noise background. Research on this subject was started during World War II by the British in an effort to explain the performance of radar operators. It had been observed that the longer the operator was on watch, the more signals that were missed. Since that time, a great deal of research has been conducted to identify variables that effect the rate and amount of performance decrement (Davies and Tune, 1969).

This area of research has wide applicability to both civilian and military situations if properly designed. As systems become increasingly more complex, man's role frequently becomes one of monitoring system state devices for malfunction warnings, etc. In many instances this task can be considered monotonous even though it may be a crucial component of the overall system. A decrement in the operator's vigilance may result in errors which could remain undetected for long periods of time or may precipitate immediate catastrophic results. Grandjean (1975) notes

that boredom, a special factor in fatigue, leads to a decrease in vigilance which may result in accidents. He goes on to say that work which cannot maintain the operator's interest or for which motivation is insufficient is a primary cause for boredom. Teichner (1972) indicates that the performance decrement is essentially complete in about 35 minutes. McGrath et. al. (1960) note that several researchers have found subgroups of between 20 to 50 percent of the experimental subjects which suffer little or no performance decrement as a function of time. The longer the human operator performs a task without detecting a signal, the more likely it is that he will become bored. Noting the speed of decrement onset, it seems increasingly more important to identify those people who will suffer little or no decrement prior to using them on tasks which may induce boredom. This author's experience includes many at-sea situations which qualify as vigilance tasks. A transit with no ships in company must certainly qualify as vigilance tasks for CIC personnel and lookouts. There are long stretches of time when no radar contacts appear and nothing is on the horizon. It is difficult to remain attentive at such times even though it may be essential to do so. The fantail watch is supposed to detect men overboard among other things — he may never get a signal but must remain alert. These and many more situations closely parallel the vigilance task and could be improved through properly conducted research.

McGrath, et. al. (1960) conducted research aimed at identifying psychological tests which could be used for predicting a subject's performance on a vigilance task. They found that predictions based on psychological tests were not consistent across tasks. Buckner, et. al. (1960) studied individual differences on vigilance tasks and found that these differences accounted for much of the variance in detection measures and were reliable over several watch periods. Other investigators have attempted to identify physiological correlates of performance. Tinsley (1969) found that systolic blood pressure, skin temperature and diastolic blood pressure were positively correlated with performance. Innes (1973) found a positive correlation between heart rate and performance, and a multivariate correlation of neck muscle tension level and sinus arrythmia were found to be significantly correlated with performance. Eason, et. al. (1965) found significant correlations between neck muscle tension level and performance. They concluded that the use of physiological parameters seems to be of value in understanding and predicting vigilance performance. As a consequence of these and other studies, this author decided to seek other physiological measures which might provide greater insight into the decrement phenomenon.

Sherman (1973) found a significant corelation existed between subjective reports of mental fatigue and performance. Davies and Tune (1969) report the results of studies which showed mental fatigue as having a detrimental effect on

performance. Critical Flicker Fusion Frequency (CFF) has been used in several studies of fatigue which demonstrated a decrease on the order of 2 Hertz from resting levels to those taken in a fatigued state (Grandjean, 1975). Grandjean also reports a lowering of the critical frequency after a long period of monotonous work. Innes (1973) found a positive correlation between fatigue and sinus arrythmia (an irregularity in heart beat). Bonsper (1970) found a negative correlation between sinus arrythmia and information processing rate. From this, one might reasonably postulate that a negative correlation may exist between fatigue and information processing rate. As a consequence, both CFF and a measure of information processing rate (IPR) were selected as dependent variables. It was expected that mental fatigue induced by the vigilance task would result in a lowered CFF and IPR. As an additional new variable, this researcher decided to use the subjects' (Ss) depth perception. Although no research was uncovered to hint at a link between fatigue and depth perception (DP), this author felt that one of the factors which helped to induce fatigue in the Ss was the relationship between the display and its background. While heart rate (HR), sinus arrythmia (SA) and neck muscle tension level (NMTL) have been used as measures in previous studies, their measurement is reasonably easy and would provide further corroboration for their usefulness as indicators of performance.

The purpose of this experiment then, is to investigate the above mentioned physiological parameters as they relate to vigilance performance.

II. METHOD

A. GENERAL

The display used for this experiment was similar to that used by Tinsley (1969). Subjects were required to observe meter deflections for a period of 40 minutes. Meter deflections were programmed to occur ar regular one-second intervals. Of the 2400 deflections, only 40 were the signal for which the Ss were instructed to watch. The signal was defined to be the slightly larger of the two sizes of deflections used (exact size differential is explained later in this section). Signal occurrence was randomly spaced by use of the random number generator of the DEC LAB 8/e computer. No attempt was made to control proximity of signals except to ensure that they were at least 4 seconds apart. The maximum delay in response allowed the subject was 3 seconds before that response was considered a false alarm (Ss did not know the allowed delay time). The LAB 8/e punched a paper tape of this random sequence of "noise" and signals. New seeds for the random number generator were used until a run was obtained with a minimum intersignal interval of 4 seconds. The 40 minute watch period was divided into 5 eight-minute time periods for purposes of future analysis but no attempt was made to ensure that an equal number of signals occurred in each segment. This is a distinct departure from previous designs.

However, this author felt this represented a more realistic situation.

The difference in size between signal and background deflections was decided upon by preliminary experimentation. Four subjects were processed before this researcher was satisfied as to the difficulty of maintaining a high detection rate over the 40 minute vigil. The size of deflections settled on was carefully measured by two people using a protractor. The measures indicated below are referenced to the horizontal and are dynamic measurements: rest, 49°; background, 114° and signal, 118°. While establishing this magnitude difference, it was discovered that a second stimulus dimension was present for a signal. The rise and fall of the pointer were distinctly faster for the signal than for the background deflections. This additional feature was not considered to be detrimental to the experiment. In fact, the trial _S_s indicated that it tended to throw them off occasionally as might be expected from a real world signal. _S_s indicated the detection of a signal by depressing a hand-held response button.

B. TEST SITE AND SUBJECTS

The experiment was performed in the Man-Machine System Design Laboratory at the United States Naval Postgraduate School in Monterey, California. All subjects were male volunteers from the student population of the school.

None of the subjects had previously participated in a vigilance experiment and received no compensation for their time. Ss were given no information about the experiment itself except that heart rate and neck muscle activity would be electrically recorded and that a maximum of 2 hours would be required.

C. APPARATUS

1. Experimental Equipment

The face of the voltmeter used for the presentation of signals measured 4 x $3\frac{1}{2}$ inches and the pointer was $2\frac{1}{2}$ inches long. The meter was disassembled and all normally visible parts were painted flat white except the pointer which was left black. The pointer driving mechanism was also hidden from view using an aluminum plate also painted white so that only a black pointer on a white background was visible. The protective glass was left off upon reassembly. The meter was placed in an Industrial Acoustics Company acoustical chamber on a table which contained an intercom slave unit and movable response button.

Electrical leads for heart rate and neck muscle tension level were fed through a wiring access to the Beckman type RM dynograph recorder which was used to record HR, SA, NMTL, signals and S's responses. The signal (larger deflections only) and response were recorded on the same channel with the signal being one-half the size

of the response. An AC coupler type 9806A was used for HR. The input of this coupler was electrically tied to the input of the Cardiotachometer coupler type 9857 to record SA. A Direct-Average EMG coupler type 9852A set for average was used to record NMTL. An AC coupler type 9806A was also used for recording signals and responses. To facilitate data reduction, SA, NMTL and one-minute time markers were recorded on Scotch Instrumentation tape using a Hewlett-Packard 3960 Instrumentation Recorder.

An Ohr-tronics paper tape reader was used to read the sequence of signal and background deflections. An Exact model 120 waveform generator was used to control presentation rate (one deflection per second). Control of signal and background deflection sizes was accomplished by using a circuit developed at the Man-Machine Systems Design Laboratory. This circuit selectively fed only the signal and response voltages to the Backman recorder. The tape reader was housed in a separate acoustic chamber in order to eliminate the loud noise it generated.

2. Electrode Placement For HR and NMTL

Physiological data for HR and NMTL was obtained by using Beckman Bipotential Skin Electrodes. Three electrodes were required for each of the measures. For NMTL, one electrode was placed on the Semispenalis Capitis muscle and one was placed on the Splenuis Capitis muscle. The reference electrode was placed on the right shoulder (Sherman,

1973). For HR, one electrode was placed over the sternum and one was placed at the bottom of the rib cage on the subjects' left side. The indifferent third electrode was placed over the subjects' abdomen on the right side. For some subjects, the sternum electrode was changed to an area less dense with hair but which would provide a good, clean signal. Prior to placement of electrodes the S's skin was cleaned using rubbing alcohol to ensure good adhesion of the electrode collars.

3. Equipment for IPR, DP and CFF

Information Processing Rate (IPR) was measured using the apparatus described by Bonsper (1970). It consisted of a counter synchronized to measure elapsed time in milliseconds, the E's control box which started the counter, a $2\frac{1}{4}$ x $1\frac{1}{2}$ inch digital display, and the S's response box which stopped the counter. Both the control and response boxes consisted of four buttons numbered 1 through 4. The E's buttons were silent and hidden from the view of the Ss. When the E pushed a button, the counter started, the display lit up the corresponding number and the Ss were required to stop the counter by deciding which number was lit and pushing that button.

Critical Flicker Fusion Frequency (CFF) was measured using a Lafayette Instrument Company model 1202A Flicker Fusion device. The unit was calibrated according to the instructions supplied by the manufacturer prior to the conduct of the experiment.

Depth Perception (DP) was measured using a Lafayette Instrument Company model 1702 depth perception apparatus.

D. PROCEDURE

The subject was asked to remove all clothing from waist up when he entered the laboratory. Electrodes were placed on his skin while the experimenter explained their purpose and precautions taken to ensure the subjects' safety. The subject was allowed to put his shirt back on if desired so that he would not be uncomfortable. Approximately 15 minutes then elapsed while the subjects' IPR, DP, and CFF measures were taken. The order of these tests was randomized for each subject so that the order in which he was processed through them would have no effect on experimental outcome. This time period also allowed any skin reactions to electrode placement to settle down and allowed Ss to become accustomed to the electrodes.

The IPR task began by showing the subjects the timer (millisecond counter), the experimenter's controls and the subject's controls and display. The manner of starting and stopping the clock was demonstrated. Ss were then seated and instructed on placement of the fingers on the response buttons. Ss were cautioned to keep their hands flat on the box and were reminded of this prior to each portion of the task. A simple reaction time was then obtained first on the left index finger then on the right. Ss were informeed that the only number they would see would be a 2 (3) and

then a sequence of twenty 2s (3s) was run and the time recorded. Next, for the 1-bit time, _Ss_ were required to differntiate between two equally likely possibilities (either a two or a three was displayed). A sequence of 50 trials was run and the elapsed time was recorded. Then, for the 2-bit time, _Ss_ were required to differentiate between four equally likely possibilities (one, two, three, or four). A sequence of 50 trials was run and the elapsed time was recorded. The actual distribution used for the two-bit trials consisted of 13 ones, 12 twos, 13 threes and 12 fours.

The CFF task was begun by showing the _Ss_ what was meant by a steady light and a flicker. _Ss_ were seated approximately 18 inches from the display and were instructed to look directly at the lamp (only one lamp was used, the other was covered by a sheet of white cardboard). The flicker frequency was set at 60 Hz and manually decreased at about 2 Hz per second. _Ss_ were instructed to inform the experimenter (E) when the lamp began flickering. This frequency was recorded and the unit was adjusted to a frequency 5 Hz below that frequency. The frequency was slowly increased and _Ss_ informed the _E_ when flickering ceased. This frequency was recorded.

_Ss_ were seated 15 feet away from the depth perception device and given the string controls. Movement of the rods was demonstrated. The _Ss_ were informed that the _E_ would place the rods in position and that they should place tension on the control strings and move their hands so they were

adjacent at the start. Two trials were run, the first with the right hand rod closer to the subject and separated from the rear rod by 40 cm. The situation was reversed for the second trial. The distance separating the rods in centimeters was recorded after each trial.

Ss were then taken to the experimental booth and seated facing the meter. Electrodes were checked and then hooked up to the Beckman leads. An elastic strap with a Velcro fastener was used to hold the wires close to the Ss so that they would not interfere with movement and to prevent electrode shifting during the experiment. The Ss were informed that they should not touch the walls of the chamber so that the signals would not be shorted out to ground. The E then told the Ss to relax and left the chamber. Recording levels on the Beckman and Hewlett Packard tape deck were checked to ensure recording would be satisfactory. Only the levels on the Beckman were adjusted when required (these were recorded on each S's chart) so that a common reference level could be used for all Ss. While reading instructions for the conduct of the experiment, a recording of S's resting HR, SA and NMTL was made. The Ss were introduced to the background and signal deflections and then given a 3-minute trial run. The signal frequency was considerably higher for the trial than for the actual vigil and feedback was provided the Ss to facilitate rapid learning. The main part of the experiment was then started. Ss were informed that the signals would not occur as frequently as they had during the trial, that no

feedback would be given and that the E would not answer any questions during the vigil. On completion of this 40 minute watch, the E entered the booth and asked the S a few questions about his performance and any irregularities he may have noticed in the movement of the pointer. The primary purpose of the questions was to allow the Ss to relax for a few minutes prior to conducting the post experiment.

The S was then told he would perform the same task but for a much shorter period of time. The maximum recovery period was 5 minutes. On completion of the post test, electrodes were removed from Ss. They then repeated the IPR, CFF and DP tasks in reverse order of that which was used prior to the main part of the experiment.

Ss were then shown their recordings and general comments about each of the facets of the experiment were made. Objectives of the E were explained and any questions the Ss had were answered. Ss were instructed prior to leaving the laboratory not to discuss the experiment with anyone who might be a participant.

E. MEASURES

1. Performance

Percent correct detections and number of false alarms were recorded for each subject during each time segment. The number of correct detections was also recorded for the 40-minute vigil to be used in a correlation analysis of performance and the IPR, CFF, and DP measures. Additionally, a measure called SCORE was developed in an attempt to penalize

those subjects with high false alarm rates. SCORE was found by subtracting the number of false alarms from four times the number of signals detected. The number 4 is arbitrary and was chosen to be that number which would raise all SCOREs above zero. In a real situation, the relationship between the costs of a missed detection and a false alarm could be calculated to provide a multiplier.

2. Physiological

HR, SA and NMTL were measured during a resting period prior to the experiment and during the last minute of each 8-minute time block during the experiment. HR was computed as the number of R-waves recorded during that minute. SA is an irregularity in the heart beat. Normally, the heart speeds up when the subject inhales and slows down when he exhales. There are other normal causes for irregularity as indicated in the introduction. The output from the Beckman then, is simply a measure of this irregularity and is derived from the time interval between two successive beats. Bonsper (1970) developed a measure of SA which consisted of drawing a line representing the average heart rate during each 1-minute time period on the electrocardiogram rate curve and measuring the area under the curve on either side of that line. The area was mechanically measured using a Keuffel and Esser Company model 1108 mechanical integrator. The number of rotations of the area wheel was then used as a measure of sinus arrythmia. The area under the integrated electromyographic signals from the neck muscles was used as

a measure of NMTL. The IPR was found by subtracting the 1-bit time from the 2-bit time for each S. This number was then divided into the number of trials (50) to obtain IPR in bits per second. CFF was computed as the simple average of the two trials as was done for DP.

F. REDUCTION OF DATA

At the conclusion of the experiment there were 7 data points for HR, SA and NMTL for each subject, 6 data points for percent detections and false alarms per subject, 2 data points for IPR, DP, and CFF for each subject. There was one data point representing each subject's SCORE and one representing the number of detections during the 40-minute vigil.

III. RESULTS

During electrical processing of the NMTL signals, a heart rate artifact was discovered and could not be filtered out. As a consequence, all NMTL data was lost. Additionally, all heart rate information was lost on one subject halfway through the main portion of the experiment.

A graphical presentation of detection performance, HR and SA is shown in Figures 1 and 2 using the mean values of those measures for all subjects. Prior to using analysis of variance (ANOVA) techniques on these measures, Cochran's test for homogeneity of variance was applied (Winer, 1962). Detection performance was the only measure which failed the test at the $\alpha = .05$ level of significance. The arcsin transformation suggested by Winer was applied to detection percentage data. The transformed data was again checked for homogeneity and failed. Since the percentage data was closer to passing the test, it was decided to use that data without the transformation and apply an appropriate caveat to the interpretation of results. A two-way ANOVA was used on detection percentage, HR, and SA to test for significant differences between time segments and _S_s as shown in Tables I through III.

From the tables it is seen that with the exception of time segments under detection percentage, all variables are highly significant. All F-values reported in this research

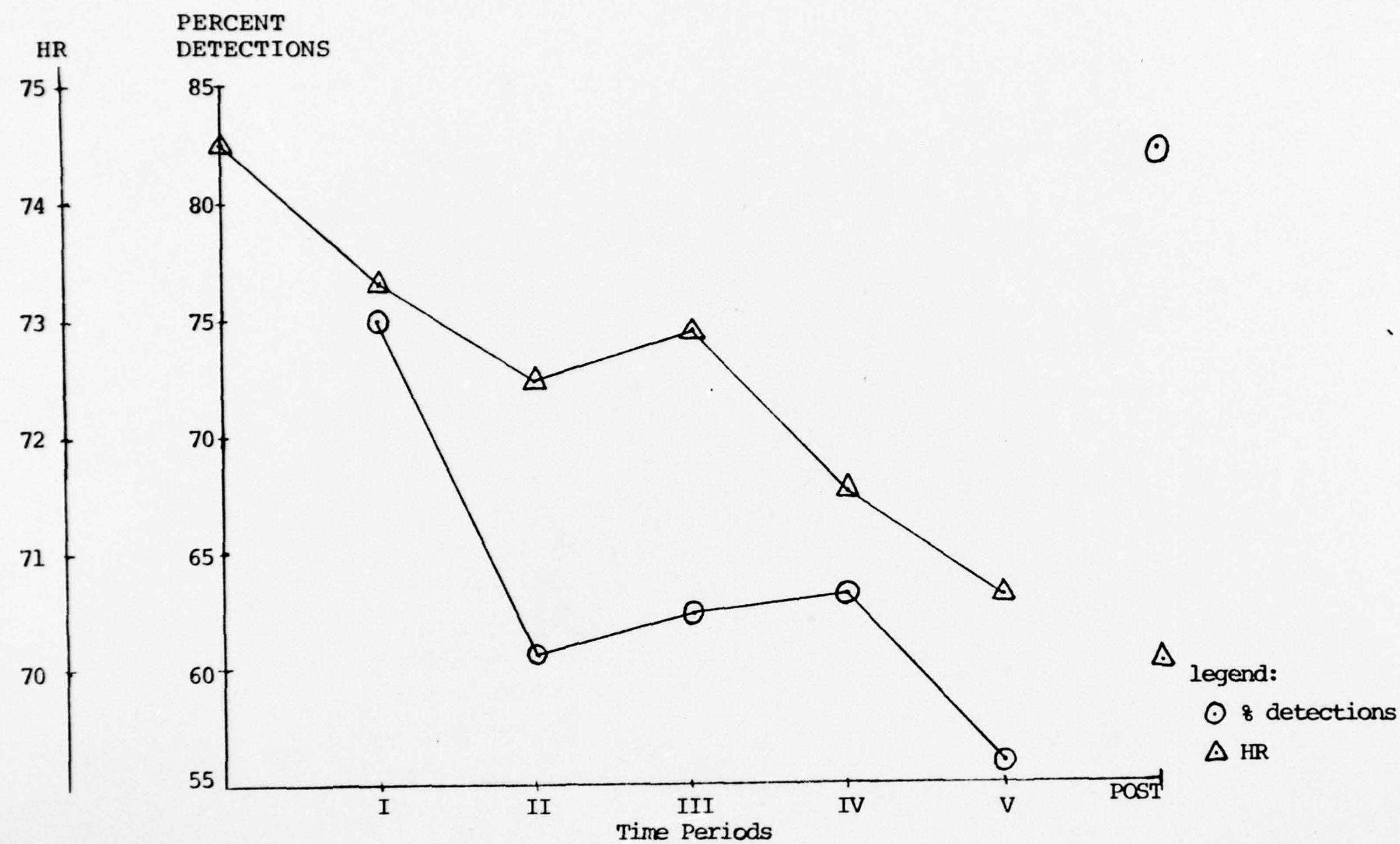
HR
75
74
73
72
71
70
PERCENT
DETECTIONS
85
80
75
70
65
60
55
I
II
III
IV
V
POST
Time Periods
legend:
% detections
HR

FIGURE 1

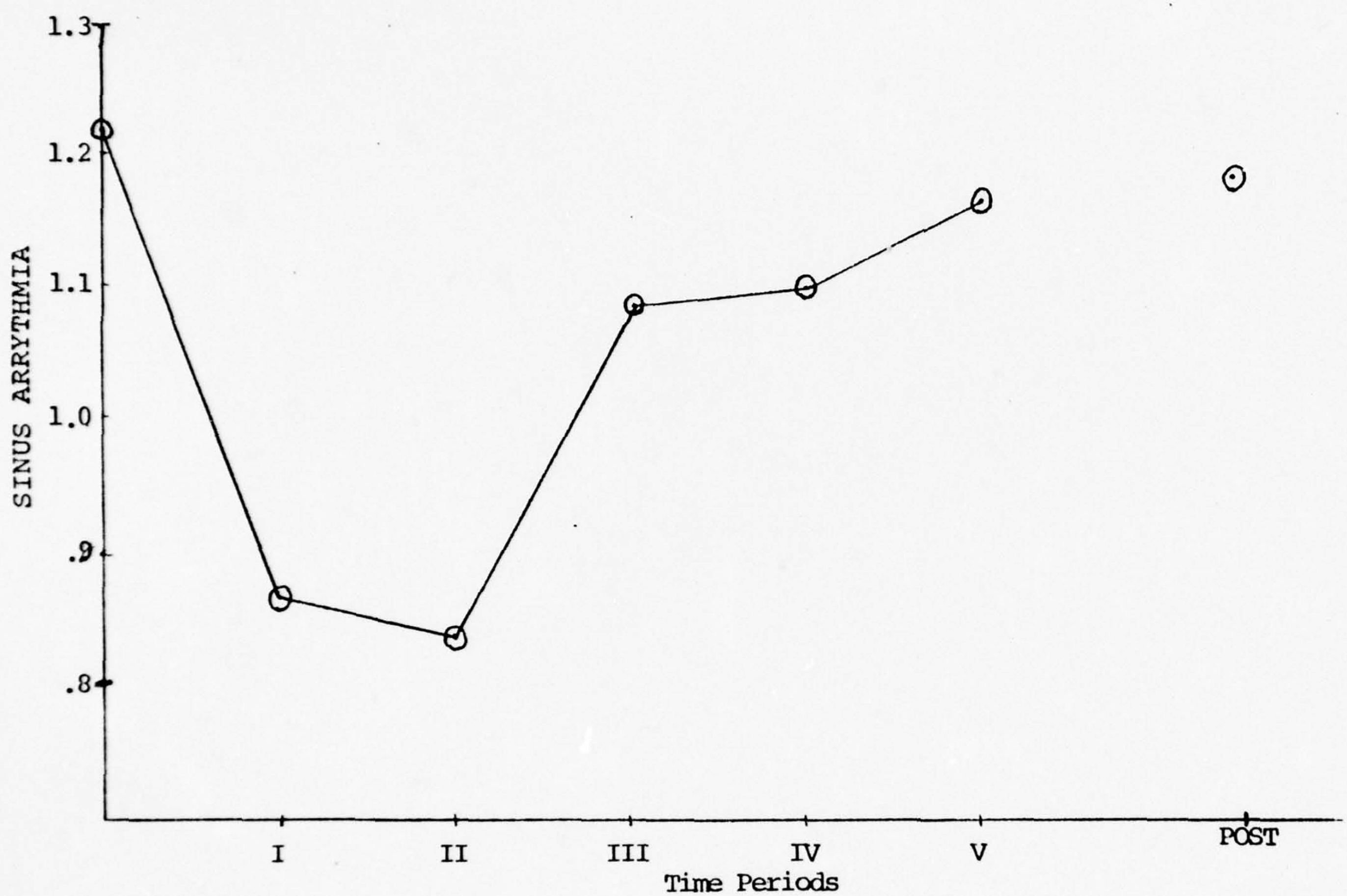

FIGURE 2

TABLE I. ANOVA on Detection Percentage

Source	df	SS	MS	F	Significance
Subjects	14	3.8	.271	7.32	<.001
Time segments	4	.3	.075	2.03	.104
Error	56	2.07	.037		
Total	74	6.17			

TABLE II. ANOVA on HR

Source	df	SS	MS	F	Significance
Subjects	13	8172.17	628.63	116.2	<<.001
Time segments	4	73.14	18.29	3.38	.016
Error	52	281.26	5.41		
Total	69	8526.57			

TABLE III. ANOVA on SA

Source	df	SS	MS	F	Significance
Subjects	13	2.49	.192	2.63	.007
Time segments	4	1.16	.29	3.97	.007
Error	52	3.81	.073		
Total	69	7.46			

were obtained using the F-distribution as supplied in the Applications Library for the Texas Instruments SR-56 Calculator.

A Friedman Two-Way Analysis of Variance (Siegel, 1956) was performed on the false alarm data to check for significant differences over time periods. Table IV shows the data after being transformed to ranks. This nonparametric test was chosen so that those few subjects which accounted for most of the false alarms would not bias the results of the test. The value for the statistic was computed from the equation:

$$\chi_r^2 = \frac{12}{Nk(k+1)} \sum_{i=1}^{k} R_j^{\,2} - 3N(k+1)$$

where: k is the number of columns

N is the number of subjects

R_j is the sum of ranks in jth column

The value of χ_r^2 computed from Table IV was 13.91. With 4 degrees of freedom, this value is significant at the .01 level.

Simple linear correlations were performed on percent detections, SA and HR to investigate the apparent trends shown in Figures 1 and 2.

TABLE IV. Friedman Two-Way ANOVA of False Alarms

	Time Periods				
Subject	1	2	3	4	5
4	4	3.5	3.5	2	1
5	2.5	2.5	5	2.5	2.5
7	2	4	3	1	5
9	5	1.5	3.5	3.5	1.5
10	3	4	5	2	1
11	5	4	1.5	3	1.5
12	5	3.5	3.5	3	1
13	2.5	5	2.5	2.5	2.5
14	3	5	3	1	3
15	5	4	1.5	3	1.5
16	2	5	3.5	1	3.5
17	4	4	4	1.5	1.5
18	5	4	1.5	3	1.5
19	1.5	5	4	3	1.5
20	5	2	4	3	1
R_j	54.5	57	49	34	29.5

TABLE V. Correlations for Figures 1 and 2

Correlates	r	t	Significance
Percent detections/HR	.7703	2.092	< .1
Percent detections/SA	-.5779	-1.226	< .25
HR/SA	-.7221	-1.808	< .1

The correlations reported in Table V were obtained using the Linear Regression package supplied by Texas Instruments. The t-values were calculated from the equation:

$$t = \frac{r}{\sqrt{1 - r^2}} \sqrt{N - 2} \qquad \text{(Downie and Heath, 1970)}$$

The significance of the t-values was found using CRC tables (Selby, 1974).

As a next step, two-way ANOVAs were used on IPR, CFF, and DP data to check for significant differences between subjects and time periods (before and after measures). These ANOVAs are shown in Tables VI through VIII.

It can be seen from Tables VI through VIII that the effects of time periods on IPR were highly significant as were the differences between subjects in DP. Time periods had relatively little effect on both CFF and DP measures as indicated by F-values less than 1. In order to further check subjects' performances against IPR, CFF, and DP (before and

TABLE VI. ANOVA on TPR

Source	df	SS	MS	F	Significance
Subjects	14	52.11	3.72	1.81	.14
Time periods	1	8.45	8.45	4.11	.062
Error	14	28.75	2.05		
Total	29	89.32			

TABLE VII. ANOVA on CFF

Source	df	SS	MS	F	Significance
Subjects	14	67.89	4.85	1.54	.215
Time periods	1	2.37	2.37	.75	--
Error	14	44.04	3.15		
Total	29	114.3			

TABLE VIII. ANOVA on DP

Source	df	SS	MS	F	Significance
Subjects	14	37.31	2.67	2.74	.035
Time periods	1	.02	.02	.02	--
Error	14	13.64	.97		
Total	29	50.97			

after measures), linear correlation techniques were used. A Pearson r correlation coefficient was obtained for each of the pairs indicated in Table IX by using the Linear Regression package supplied by Texas Instruments. The designations B (or A) appended to IPR, CFF, and DP in the table refer to before and after measures, respectively. Rather than compute a percentage of total signals detected by each subject, the total number of signals detected was used for these correlations. The t-values reported in Table IX were computed as was done for Table V.

Table X indicates the results of multiple correlations performed using Biomedical program BMD02R (Dixon, 1968). An F-level of 0.25 was used for inclusion and removal of the independent variables from the regression equations. A tolerance level of 0.001 was used for all computations. The values for the F-statistic were obtained directly from the program and significance was determined using the Texas Instruments F-distribution.

Table IX shows that both SCORE and number detected are significantly correlated with DP(B) and that the number detected is significantly correlated with CFF(B). These same factors are apparent in Table X with CFF(B) not quite so important.

TABLE IX. Simple Correlations

Correlates	r	t	Significance
SCORE/# signals detected	.623	2.87	<.01
# detected/# false alarms	.433	1.73	<.1
SCORE/IPR(B)	.027	.097	--
SCORE/IPR(A)	.02	.074	--
SCORE/DP(B)	-.573	-2.52	<.025
SCORE/DP(A)	.05	.18	--
SCORE/CFF(B)	.04	.15	--
SCORE/CFF(A)	.122	.44	<.6
# detected/IPR(B)	.005	.019	--
# detected/IPR(A)	.278	1.044	<.25
# detected/DP(B)	-.585	-2.6	<.025
# detected/DP(A)	-.044	-.16	--
# detected/CFF(B)	.492	2.04	<.05
# detected/CFF(A)	-.006	-.02	--
IPR(B)/IPR(A)	.297	1.12	<.25
DP(B)/DP(A)	.469	1.91	<.05
CFF(B)/CFF(A)	.225	.834	<.25

TABLE X. Multiple Correlations

Dependent Variable	Independent Variable(s)	R^2	F	Significance
SCORE	DP(B)	.3284	6.3559	.02
SCORE	DP(B) CFF(B)	.3803	1.005	.395
SCORE	DP(B) CFF(B) IPR(B)	.4173	.6995	--
NUMBER DETECTIONS	DP(B)	.3428	6.7807	.017
NUMBER DETECTIONS	DP(B) CFF(B)	.4138	1.4528	.27
NUMBER DETECTIONS	IPR(A)	.0774	1.0902	.297
NUMBER DETECTIONS	IPR(A) DP(A)	.1552	1.105	.363

IV. DISCUSSION

A. GENERAL

As stated in the introduction, it was expected that participation in the vigilance task would reduce both CFF and IPR measures from the pre-test levels. The mean CFF after the experiment was higher than it was before. This difference was shown to be insignificant (over time periods) in Table VII. Grandjean (1975) stated that CFF has been shown to decrease with increasing fatigue. A possible explanation for the decrease not showing up in the present research is that an insufficient number of data points were collected on each subject. The mean IPR was also higher after the experiment and was shown to be significant at the .062 level. It appears that the experimental conditions had a positive effect on IPR in contrast to the expected results. The mean error on the DP test also showed a decrease after the experiment but as shown in Table VI, the difference is not significant. Again, it may be that an insufficient number of data points were collected on each subject. Of these three measures, pre-test DP seems to be the most promising from a predictive standpoint. Table VI indicated a significant ($p = .035$) difference between subjects which is a desirable quality of predictors.

The pre-test CFF also showed promise as a predictor as indicated by the simple linear correlation coefficient with

number of detections. Again, more data points on each subject may improve the utility of this measure as a predictive tool.

The lack of any significant correlation between IPR and performance as well as its instability over time seems to negate its usefulness in future research.

The idea of penalizing those Ss with high false alarms rates by calculating a performance SCORE may have some merit but it is not evident from the analysis. The R^2 values shown in Table VIII using both SCORE and number detected as performance measures are within experimental error of each other. This may be due in part to the arbitrary manner in which SCORE was defined. Primarily it is because SCORE and number of detections were used to measure the same thing.

Signal frequency is an important consideration in the design of any vigilance experiment. Davies and Tune (1969) report the results of several researchers who have studied the importance of this variable. The general conclusion was that the higher the signal frequency, the greater the number of detections (excluding extremes). In the present research, signal frequency was deliberately varied from one time block to the next. Appendix B is a list of the signal times. Figure 1 indicates that the decrement was as fast (if not faster) during the second time period as could have been expected during the first period. During the third and fourth periods, detection is seen to improve even though signal density is half of what it was during the second time

segment. Performance is seen to fall off again during the fifth period even though signal frequency is twice what is was during the fourth time segment. Table I shows the differences in mean percent detections over time periods to be significant at the $\alpha = .104$ level. The decrements registered from the beginning of the third period to the end of the fifth are statistically insignificant leading this researcher to believe that the decrement was essentially complete after only 16 minutes. The slight increases during the third and fourth time segments may be due to some form of delayed arousal. Had the experiment been longer, the same effect may have been observed during the sixth and seventh periods as a result of the high density during the fifth period.

HR showed a highly significant decrease as a function of time on watch (Figure 1). The correlation coefficient of 0.7703 was shown to be significant at the 0.1 level in Table V. This finding may be added to those of Innes (1973) in which a positive correlation significant at the 0.2 level was found between HR and detection performance.

Figure 2 shows an initially fast decrease in SA as the Ss begin the experiment. This is consistent with the findings of Bonsper (1970) if one assumes that Ss were properly motivated. After 16 minutes the curve climbs rapidly possibly indicating the onset of boredom. This is also the point where the decrement is essentially complete (in this author's opinion).

B. APPLICATION

A study by Smith and Tucaccini (1969) states as one of its conclusions:

> ...It is concluded that: (1) little or no evidence exists indicating that the oft-found decrement in the laboratory has a parallel in the industrial (or military) setting...

Their study was based on a review of recent literature and cited the results of one study in which CIC personnel, in a mock-up of an actual CIC, showed no decrement after continuous 4 $\frac{1}{2}$ hour vigils over a period of 5 days. Unfortunately, this author was unable to obtain a copy of the study. If the participants knew they were being used in an experiment, received detailed instructions, were not at sea, etc., they may as well have been in a laboratory.

This author contends that laboratory studies are useful if only to pinpoint areas which show the most promise for results in "real-life" situations. Further, a CIC crew that has been at sea for a few days, perhaps with one or two contacts a day, certainly suffers vigilance decrements based on this author's experience. The same can be said for the lookouts.

It is not likely that any laboratory experiment will ever duplicate the situation being studied when human performance is a variable. With proper motivation and a certain amount of realism (as attempted in this study) a starting point may be found so that studies in the real situation may be undertaken. As an example, this research

indicated that heart rate and depth perception may account for a large amount of variation in performance. These two measures are quickly taken and do not require expertise. Both could be measured at sea as often as desired and compared with performance. After a short while, sailors might forget they were being studied and settle down to their "normal" performance pattern at which time useful, real-life data could be obtained. The investment in time may amount to 15 minutes a day and may result in a truly significant relationship. When a relationship is identified, it could be used to determine who should or should not be assigned to tasks which involve the type of task studied.

C. RECOMMENDATIONS

In view of the findings presented in this paper, further research is indicated on depth perception, critical flicker fusion frequency, and heart rate in relation to vigilance performance. It may also be possible to combine these measures with some psychological measures previously studied (McGrath, et al., 1960) to produce a truly significant multiple correlation coefficient.

APPENDIX A

INSTRUCTIONS TO SUBJECT

On the table before you is an intercom; to use it simply peak — you need not push any buttons. Am I speaking loudly enough for you? Also on the table is a response button and a meter. Please hold the response button in either hand throughout your watch. Depress the response button now.

Do not touch the meter or move the table. Specifically, do not hold your hand or any other object up in front of the meter so as to cast a shadow. Seat yourself facing the meter so that you are able to view it comfortably. Refrain from touching any electrodes or their connecting wires. Please avoid any gross body movements such as standing as these may cause a shift in electrode placement. Address your attention to the meter. There are two deflection sizes used for this experiment. To demonstrate, you will now see 5 groups of two deflections each. In each group, the second deflection will be slightly larger than the first. The difference is small — PLEASE PAY CLOSE ATTENTION. Did you see the difference?

Throughout your watch, the pointer will deflect at regular one-second intervals. Most will be smaller sized deflections but occasionally and at random intervals, a slightly larger deflection will occur. It is this larger

deflection which you are to report by depressing the response button.

Now I will run a short trial so that you may become familiar with the signal and your method of response. Again, depress the response button only when you see the larger deflection. I will provide verbal feedback as follows:

"hit" means a correct response

"miss" means you missed a signal

"false alarm" means an incorrect response

Any questions? The trial begins when the pointer starts deflecting.

Do you feel fairly certain of the signal now?

We will start the watch. Everything will be as it was for the trial run except that the signal will not occur as frequently and I will not provide you with feedback. Please bear in mind that although this particular task may not seem relevant to anything you may have done, or may do in the future, you should conduct yourself as though it were an extremely important one. I will not respond to any questions during the watch. Do you have any at this time? Please do your best to report only the larger deflections. The watch will start when the pointer begins moving and will end when the pointer comes to rest. Please remain seated at that time.

- - - -

Please remain seated. I will enter the booth and give you a questionnaire to fill out. When you complete it, you

will stand another watch of much shorter duration. The same instructions apply to this watch. It will start when the pointer begins moving.

APPENDIX B

SIGNAL DISTRIBUTION

00:34	18:16
00:59	18:31
1:34	20:30
1:49	22:54
4:04	23:18
4:09	24:06
5:42	25:40
7:47	27:56
8:35	28:06
9:05	31:14
9:35	32:15
12:06	33:58
12:42	35:33
12:49	36:07
13:15	36:36
14:04	37:07
14:35	37:46
14:52	37:50
15:21	38:14
16:55	39:33

The Post-test consisted of a repeat of the first 8 minutes of the main schedule above.

APPENDIX C

RAW DATA

Subject Number	Detection Percentage						Heart Rate						
	I	II	III	IV	V	Post	B	I	II	III	IV	V	Post
4	.625	$.\overline{45}$	$.\overline{33}$	.4	.4	.625	52	53	51	51	53	50	49
5	.5	$.\overline{63}$	$.8\overline{33}$	1	.8	.875	80	75	75	74	74	73	72
7	.625	$.\overline{81}$	.5	1	.5	.875	59	58	58	58	56	64	59
9	.75	$.\overline{18}$	$.1\overline{66}$	.4	.5	.875	86	88	87	88	84	82	81
10	.75	$.\overline{81}$	$.\overline{66}$	.8	.7	.625	88	85	88	85	83	82	83
11	.5	$.\overline{27}$	$.\overline{33}$	.4	.4	1	69	70	64	72	67	62	70
12	1	$.\overline{81}$	$.8\overline{33}$	.6	.3	.75	53	52	53	57	56	55	56
13	.625	$.\overline{27}$	$.\overline{33}$	0	0	.75	79	80	78	81	79	73	75
14	.875	$.\overline{81}$	.5	1	1	.625	83	83	81	76	80	79	78
15	.875	$.\overline{45}$	$.8\overline{33}$	1	.8	1	66	66	66	67	65	67	64
16	.875	$.\overline{81}$	1	1	1	1	82	75	78	73	70	70	69
17	.875	$.\overline{54}$	.5	0	.3	.625	89	85	79	81	82	81	78
18	.875	$.\overline{90}$	1	1	.9	1	78	71	72	72	69	70	67
19	.625	$.\overline{45}$	.5	0	.1	.625	-	-	-	-	-	-	-
20	.875	$.\overline{81}$	1	.8	.7	1	79	86	85	85	83	79	79

Subject Number	# False Alarms I	II	III	IV	V	Post	B	Sinus Arrythmia I	II	III	IV	V	Post	SCORE
4	4	3	3	1	0	0	1.16	.8	.5	1.0	1.22	1.04	1.08	61
5	0	0	1	0	0	0	1.7	1.1	.76	1.26	1.14	1.28	1.1	115
7	14	17	15	11	20	25	1.04	1.22	1.1	.74	1.76	2.26	2.24	6
9	10	1	2	2	1	3	1.6	.92	.86	1.58	1.24	1.46	1.76	48
10	5	8	9	2	0	1	.7	.96	.78	.48	.74	1.0	.9	96
11	8	4	1	2	1	1	.97	.54	.48	1.24	.8	.68	.98	40
12	16	11	11	3	2	20	1.24	.68	.66	1.66	1.38	1.1	1.0	69
13	0	2	0	0	0	0	.8	.8	.96	1.7	.94	1.2	.86	38
14	1	5	1	0	1	0	1.24	1.24	1.08	1.38	1.22	1.0	1.16	128
15	3	2	0	1	0	0	1.5	1.06	.9	.74	1.16	.96	1.14	114
16	18	28	19	17	19	13	.92	.66	1.18	.92	.66	.96	.92	47
17	2	2	2	1	1	0	1.18	1.0	1.2	.94	1.34	1.1	1.22	68
18	15	7	2	3	2	5	1.96	.88	.74	.78	1.12	1.18	.74	119
19	2	6	5	3	2	4	--	--	--	--	--	--	--	38
20	14	1	5	3	0	5	1.3	.52	.6	.78	.74	1.1	1.38	109

Subject Number	IPR		DP		CFF	
	B	A	B	A	B	A
4	4.81	4.92	2.25	.5	42.95	42.8
5	7.13	5.67	1.3	1.65	43.4	48.33
7	5.49	8.63	3.5	1.1	44.55	46.0
9	6.19	8.87	4.9	6.05	44.85	44.3
10	6.89	9.75	1.25	1.2	45.15	46.1
11	8.76	6.93	2.6	2.1	43.9	45.05
12	4.29	5.09	.55	.2	45.0	44.8
13	5.96	5.45	2.85	.6	42.7	45.0
14	5.34	5.47	1.05	1.05	46.5	49.05
15	5.53	10.31	.55	2.35	44.55	42.7
16	4.95	8.27	.7	1.1	49.15	43.65
17	4.8	5.28	2.15	.75	45.35	44.4
18	7.08	8.54	.9	2.2	45.5	44.6
19	6.75	8.54	.8	1.95	47.0	50.85
20	9.82	7.99	1.25	3.05	45.45	46.8

BIBLIOGRAPHY

1. Buckner, D.N., Harabedian, A., and McGrath, J.J., "A Study of Individual Differences in Vigilance Performance," Human Factors Research, Inc., Technical Report 2, 1960.

2. Davies, D.R. and Tune, G.S., Human Vigilance Performance, p. 58-63, 80-117, 160-161, American Elsevier Publishing Company, 1969.

3. Dixon, W.J., Biomedical Computer Programs, University of California Press, 1968.

4. Downie, N.M. and Heath, R.W., Basic Statistical Methods, p. 230-232, Harper and Row, 1970.

5. Eason, R.G., Beardshall, A. and Jaffe, S., "Performance and Physiological Indicants of Activation in a Vigilance Situation," Perceptual and Motor Skills, v. 20, p. 3-13, 1965.

6. Grandjean, E., Fitting the Task to the Man – An Ergonomic Approach, p. 59-70, Taylor and Francis Ltd, London, 1975.

7. Innes, H.E., Subjective and Physiological Indicators of Fatigue in a Vigilance Task, Masters Thesis, Naval Postgraduate School, Monterey, 1973.

8. McGrath, J.J., Harabedian, A. and Buckner, D.N., "An Exploratory Study of the Correlates of Vigilance Performance," Human Factors Research, Inc., Technical Report 4, 1960.

9. Seigel, S., Nonparametric Statistics for the Behavioral Sciences, p. 166-172, McGraw Hill, 1956.

10. Selby, S.M., CRC Standard Mathematical Tables, 22d ed., CRC Press, 1974.

11. Sherman, M.R., The Relationship of Eye Behavior, Cardiac Activity and Electromyographic Responses to Subjective Reports of Mental Fatigue and Performance on a Doppler Identification Task, Masters Thesis, Naval Postgraduate School, Monterey, 1973.

12. Smith, R.L. and Lucaccini, L.F., "Vigilance Research: Its Application to Industrial Problems," Human Factors, v. 11(2), p. 149-156, 1969.

13. Teichner, W.H., "Predicting Human Performance III: The Detection of a Simple Visual Signal as a Function of Time on Watch," New Mexico State University Technical Report 72-1, 1972.

14. Tinsley, J.H., An Investigation of Physiological Correlates of Vigilance Performance, Masters Thesis, Naval Postgraduate School, Monterey, 1969.

15. Winer, B.J., Statistical Principles in Experimental Design, p. 94, 218-224, McGraw-Hill, 1962.

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